In order to be miniaturized and to attain high-density at a high rotational speed, the rotational accuracy of a rolling bearing for use in the spindle of a magnetic disk driving device must be satisfactory in order for the magnetic disk driving device to achieve high-density. Lower bearing rotational accuracy results in a larger position gap between the record track of a recording medium and a recording head and a larger record track width and pitch.

Accordingly, in the claimed invention, in order to improve the rotational accuracy of the rolling bearing and to decrease residual austenite $r_R$ which is most deleterious to bearing rotational accuracy, the amount of residual austenite over the entire cross section of one of the inner ring, the outer ring and the rolling element is set to be 0% by volume. This is the first point of the claimed invention.

The reasons are as follows:

(a) Since $r_R$ becomes softer due to the martensitic structure formed by hardening, it tends to cause plastic indentation or local permanent deformation on the raceway surface of the bearing ring under impact forces. Therefore, an object of the present invention is to prevent this phenomenon by reducing $r_R$ to zero.

(b) Because of the demands of miniaturization of HDD spindles and the like, the thin bearing ring (for example, a thickness of about 1 mm) has been used under high load in many cases. In these circumstances, the contact pressure between a rolling element and the raceway surface of the bearing ring becomes high, and high contact pressure tends to cause unevenness due to permanent deformation etc. Therefore, an object of the claimed invention is to prevent this phenomenon.

In addition, plastic indentation and permanent deformation cause vibrations during rolling bearing rotation and inevitably reduce rotational accuracy of the rolling bearing.

The second point of the claimed invention is to provide a rolling bearing which has a long service life and can endure repetitive shearing stresses under a high surface pressure applied to the raceway surface of the bearing ring.

Further, the claimed invention is to provide a rolling bearing which has high impact resistance to prevent permanent deformation and is excellent in acoustic characteristics and in maintaining rotational accuracy for a long duration.

Accordingly, in the claimed invention, the surface hardness of the raceway surface of the inner and the outer ring and the rolling surface of the rolling element is set to be HRC of 62 or more.

Since it was difficult to decrease the amount of residual austenite over the entire cross section of the bearing ring to 0% by volume while the surface hardness is increased to HRC 62 or more, a main feature of the claimed invention is to overcome such difficulties by using the steel material of the claimed invention and applying a hardening and tempering treatment at a high temperature with low costs, instead of applying a high cost heat treatment, such as carburization or carbonitriding.

In order to reduce $r_R$ to 0% by volume, in the case of the steel material shown in Tab 1, it is discovered that the tempering temperature is preferably 240°C or more as shown in Fig 2, and even at such a low tempering temperature, the surface hardness of HRC 62 or more can be obtained.

By making these two characteristics compatible, a rolling bearing is invented which is excellent both in impact resistance (Tab 1 and Tab 5) and acoustic characteristics (Tab 3 and vibration characteristics).

In the claimed invention, the principal elements which are necessary to assure the compatibility of $r_R$ =0% by volume and the surface hardness of HRC 62 or more, are determined as follows.

C: The lower limit is set to be 0.8% for a surface hardness of HRC 62 or more while the upper limit is designated as 1.2% or less for controlling the excessive amount of $r_R$ % by volume.

Si: The upper limit is 0.6% for controlling and stabilizing $r_R$.

Mn: The upper limit is set to be about the same as Si for controlling and stabilizing $r_R$.

Cr: It is used to improve hardenability and to ensure the surface hardness of HRC 62 or more. At the same time, the carbide is formed (spherical shape) to improve rolling fatigue life.

Mo: It is the most unique element according to the claimed invention to make $r_R$ =0 even when the tempering temperature is 240°C or more. In order to make the surface hardness not to be lower than HRC62 due to softening, 0.60-1.50% of Mo is added and it is the element which improves tempering resistance.

As mentioned above, the claimed invention specifies a steel including C, Si, Mn, Cr and Mo and combines these elements organically in order to make $r_R$ =0 for the entire cross section of the rolling parts, and to maintain the surface hardness of

HRC62 or more, even at the tempering temperature of 240°C or more. Accordingly, the claimed invention improves impact resistance, acoustic characteristics and acoustic life, and it does not intend to improve dimensional stability only.

## 2. On Cited References

### *2.1 Matsumoto et al. (U.S.P. No. 5, 122,000)*

Although Tab 1 of Matsumoto et al. shows the composition of the alloy steels of Matsumoto et al., none of the alloy steels of Matsumoto et al. satisfies all the ranges of C, Si, Mn, Cr, Mo of the present invention at the same time.

If Table 1 is vertically seen for each ingredient of steel of the claimed invention, C% of steel piece K, and Cr % of steel piece A only satisfy the ranges of the claimed invention, and steel piece K is a comparative steel of Matsumoto et al.

Regarding $r_R$, Matsumoto discloses that the dimensional stability of the bearing is better when the average concentration of the retained austenite present in the ball bearing is lower, and the average concentration of the retained austenite defined to be less than 10% so that the dimensional stability of the rolling bearing of the claimed invention is equivalent to or superior to that of the bearing steel No 2 (SUJ-2).

However, Matsumoto et al. actually discloses that the minimum average of $r_R$ is 6.4 (see Table 7) and $r_R$ on the surface is 20% vol or more and $r_R$ in the core portion is 5% vol or less as (see the amount distribution of $r_R$ in Fig. 9).

### *2.2 Mitamura (U.S.P. No. 5,626,974)*

Mitamura discloses a rolling bearing for use in industrial machines and the like under high temperature conditions, typically 130°C or more. The rolling bearing includes an inner ring, an outer ring and a plurality of rolling elements which ARE made of a high carbon steel and has a Rockwell hardness of HRC 60 or more.

The high carbon steel includes a solid solution of carbon C and a solid solution of nitrogen N which are adjusted to satisfy 0.8 wt%<C<1.2 wt% and 0.1wt%<N<0.5% wt%, in order to apply hardening at a reasonable temperature and to improve the bearing endurance.

The retained austenite in every part of the bearing is adjusted to 0 vol% by tempering at the temperature of 270 to 300°C, in order to improve dimensional stability.

The main feature of Mitamura's invention is that considering the decomposition of retained austenite in the surface, the bearing must be subjected to tempering at 270°C or more after carbonitriding and hardening in order to reduce retained austenite to 0 vol%. As a result, bearing endurance is significantly affected by the contents of solid solution of carbon C and solid solution of nitrogen N.

However, Mitamura only discloses that the steel is SUJ-2, and this steel does not contain Mo.

Moreover, it is clear from Table 1 that the Rockwell hardness of Run No. A (minimum) and C (maximum) are 61.4 and 61.8 respectively, and they are lower than HRC 62 of the claimed invention.

### *2.3 Murakami et al. (U.S.P. NO. 5,352,303)*

Murakami et al. discloses a rolling bearing which has good rolling fatigue for use in transmissions or the like. The rolling bearing includes an inner ring, an outer ring and rolling elements which are made of an alloy steel containing C: 0.1 to 1.0 wt%, Cr: 0.5 to 3.0 wt%, Mo: 0.10 to 2.0 wt%, Si: 0.15 to 1.0 wt%, Mn: 0.20 to 1.5 wt% and Ni: 0.2 to 1.0 wt%. The alloy steel is subjected to carbonitriding at 820°C, hardening and tempering at 180°C, so that the total content (C+N) of C and N in the surface layer is 1.0 to 2.0 wt%, and the ratio N/C is 0.8 to 2.0.

As a result, the rolling bearing is improved not only in rolling fatigue life but also in wear resistance, in seizure resistance, and in tempering resistance.

However, Murakami et al. does not disclose the amount of the retained austenite at all.

### *2.4 Tanaka et al. (U.S.P. NO. 6,086,686)*

The Examiner quoted what is the third embodiment of Tanaka et al. (column 12, lines 22 to 26, and lines 40 to 43). The rolling bearing has a plurality of rolling members each comprising an outer race, an inner race or a shaft element, wherein at least one of the rolling members is formed of a steel having secondary hardenability and a nitride layer of 2% or less along the diameter $D_a$ of a rolling element on a surface layer of a finished article.

The nitride layer comprises Cr nitride layer and Fe nitride layer, and is nitrided at a temperature of 480°C or less. Addition of such a nitride layer to the bearing material can prevent adhesion, decrease friction and significantly improve fretting damage.

Further, the steel of Tanaka et al. contains C: 0.45 wt% or less, N: 0.05 wt%, Cr: 12.0 to 13.5 wt%, Mn: 0.1 to 0.8 wt%, Si: 0.1 to 1.0 wt%, Mo: optionally 0.3 wt% or less and C+N is 0.5 wt% or more.

The above steel was hardened at a temperature of 1020 to 1070°C, and then, secondarily hardened at 450°C for 2 hours, which is followed by cutting. Then, a nitride layer with a depth of about 20 μm was formed as a surface layer by the gas nitriding method at 410°C for 24 hours, which followed by finishing.

Table 8 shows that the surface roughness after nitriding is 0.18 Raμm (but the Examiner said that it is 0.27 Raμm).

However, in Tanaka et al., although the subject matter for the rolling element was disclosed, there is no disclosure of the subject matter of the raceway ring at all.

**3. <u>The Differences between the Cited References and the Claimed Invention</u>**

***3.1 Claims 1, 2, 4, 11 and Matsumoto et al., Mitamura, Murakami et al.***

The common subject matter of claims 1, 2, 4 and 11 (although claim 3 is also the same) are that one of an inner ring and an outer ring is formed of a steel which is subjected to hardening and tempering, and the amount of residual austenite over

its entire cross section is set to 0% by volume and the surface hardness is set to HRC 62 or more.

*3.1.1 Matsumoto et al.*

As described in the last response, none of the steel species in Table 1 of Matsumoto et al. satisfies the range of the alloy steel of the claimed invention. The Examiner selectively used the ranges of C, Si, Mn, Cr, Mo from Table 1 based on hindsight provided by Applicant's disclosure.

As described in the specification of the present application (page 3, line 14 to page 4, line 4), in order to improve tempering resistance, to reduce manufacturing cost in comparison with carburization, quenching and tempering, and to be able to utilize the process of manufacturing SUJ2 steel, such as hardening and tempering, the SUJ2 steel is used as the main components of the claimed invention and Mo is added, but as little as possible.

Accordingly, it simultaneously realizes that $r_R$ over the entire cross section of the bearing ring is reduced to 0 vol% and the surface hardness is HRC 62 or more, which has not been attained in the SUJ2 steel.

On the other hand, in Table 1 of Matsumoto et al., the contents of C% for steel species A to I, and for comparative steel species M to N are all lower than that of the claimed invention, and the steel of Matsumoto et al. was subjected to carbonization. Since the maximum particle size of carbides for J, K and L is over 6 μm, they are excluded from the life evaluation test at the beginning.

Therefore, the steel of Matsumoto et al. uses carburization and hardening, and, unlike the claimed invention, does not use the low cost heat treatment methods, such as quenching and tempering.

Further since Cr in Matsumoto et al., is added as an element to form fine carbides and attain high surface hardness of HRC 64 to 69, the content of Cr greatly exceeds the upper limits of the claimed invention exception for steel species A.

As mentioned above, the steel species of Matsumoto et al. are made on the assumption that they will be subjected to carburization and carbides of 6 mm or less at the depth of 2% $D_a$.

Since carburization treatment is a precondition, the base carbon of the steel species shown in Table 1 is low and the content of C wt% on the surface is higher than that in the core portion. As seen in Figure 15 of Attachment I, $r_R$ increases as C increases.

As a result, as shown in Fig. 9 of Matsumoto et al., $r_R$ on the surface, which has high C%, exceeds 20 vol% while $r_R$ in the core portion, which has low C%, is less than 5 vol%.

Therefore, it is clear that in Matsumoto et al. there is no disclosure of setting $r_R$ over the entire cross section to 0 vol% at all.

*3.1.2 The Differences in the meaning of $r_R$ (for impact resistance in the claimed invention and for dimensional stability in Matsumoto et al.)*

Regarding dimensional stability, as shown in Fig. 9 of Matsumoto et al., even if there is much more $r_R$ (Vol%) on the surface, if the average $r_R$ is less, dimensional

change of the whole raceway ring accompanying the martensitic transformation of $r_R$ will become small.

However, with respect to impact resistance, since impact force is applied to the raceway surface of the raceway ring, it is obvious that the raceway surface can be easily damaged when the raceway surface is softer due to high $r_R$ %.

That is, although a low value of total $r_R$ vol% is enough for dimensional stability, it is very important for impact resistance to set $r_R$ on the raceway surface to 0 vol%. In the claimed invention, $r_R$ is 0 Vol% over entire cross section and at least on the surface.

Therefore, even if there is thought of dimensional stability in Matsumoto et al., there is no thought of impact resistance which is an object of the claimed invention.

*3.1.3 Mitamura*

Although Mitamura discloses that $r_R$ is 0 vol%, as mentioned above, since the steel of Mitamura is made using carbonitriding, surface solid solution of nitrogen (for adding tempering resistance), and tempering at 270 to 300°C, it does not have the improved tempering resistance of the claimed invention due to the added Mo of the claimed invention.

Although both Mo (the claimed invention) and (C+N) (Mitamura) increase tempering resistance, the hardening hardness before tempering is high for Mo. The Attachment III hereto shows the relationship between hardness and tempering temperature.

If Mo is added in advance to the material, since a martensitic transformation is promoted during quenching to improve hardenability, hardness after quenching becomes high.

On the other hand, the quenching hardness after adding C+N will almost be saturated if C+N exceeds 0.8% wt%, and the increase of this value will result in increased amount of $r_R$ vol% (see Attachment I). However, it will reduce hardness, resulting in less impact resistance etc.

Accordingly, not only for reduction in heat treatment cost, but also for surface hardness after tempering, Mo is advantageous over C+N.

This is why the surface hardness in Table 1 of Mitamura ranges between a minimum of HRC61.4 and a maximum of HRC 61.8.

*3.1.4 Murakami et al.*

Although Murakami et al. discloses a rolling bearing in which the steel overlaps the range of composition of the claimed invention, the steel of Murakami et al., like Mitamura, is made by means of carbonitriding, and fine carbides form on the surface of the rolling member. Murakami et al. does not teach that $r_R$ is 0 vol%.

As shown in Attachment II hereto (Machine and Metal Material for Young Engineers, Page 175), tempering resistance is improved by performing solid solution of Mo and Cr in the martensitic structure, which is a matrix. It is not accomplished by consuming these two elements as carbides, as described in Murakami et al.

Therefore, Murakami et al. does not disclose the features of the claimed invention that $r_R$ over the entire cross section is 0 vol% and, at the same time, surface hardness is HRC 62 or more.

As mentioned above, because of Matsumoto et al., Mitamura and Murakami et al. do not disclose or suggest that $r_R$ is 0% by volume over the entire cross section and the surface hardness of the raceway is HRC of 62 or more, it is not obvious to combine Matsumoto et al., Mitamura and Murakami et al. to arrive at the claimed invention.

Therefore, the rejection of claims 1, 2, 4 and 11 under U.S.C. § 103 is improper.

4. **Claim 3**

Although Tanaka et al. discloses a rolling member in which a nitriding layer on the surface is similar with that of claim 3, Mitamura and Murakami et al., and Tanaka et al., like Matsumoto et al., do not teach the raceway ring of the present invention, and do not teach the purpose, function and effect of the claimed invention neither.

Therefore, it is not obvious to arrive at the claimed invention by adding Mitamura, Murakami et al. and Tanaka et al. to Matsumoto et al.

If there are any questions regarding this amendment or the application in general, a telephone call to the undersigned would be appreciated since this should expedite the prosecution of the application for all concerned.

If necessary to effect a timely response, this paper should be considered as a petition for an Extension of Time sufficient to effect a timely response, and please charge any deficiency in fees or credit any overpayments to Deposit Account No. 05-1323 (Docket #313MC/48531).

Respectfully submitted,

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